JOINT AUSTRALIAN/UK STACK FRAGMENTATION TRIALS

PHASE 4 PRELIMINARY REPORT

Presented to the 24th Explosives Safety Seminar

by

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SUMMARY

This is a Report of Phase 4 of the Joint Australian/UK Stack Fragmentation Trials. This particular trial was designed to quantify the explosion effects, i.e. blast and debris, that would be expected to arise as a result of an accidental explosion in a UK designed NATO Standard Igloo explosives storehouse. The report describes the specification of the trial, the support work required and examines the results of the debris collection and the blast measurement records. Additional work was also carried out to attempt to ascertain the initial velocity of the structural debris from the donor and this is described in outline detail only.

The trial was coalesced with the Australian Explosive Store-House Design Trial in which three Australian designed "Spantech" arch earth-covered magazines were constructed at appropriate inter-magazine distance at side to side, front to rear and rear to front orientations, relative to the donor igloo. These were instrumented internally to ascertain their structural response to the blast from the donor igloo and externally to ascertain the typical blast loadings that would be expected on adjacent igloos in the event of the donor accidentally exploding. The aim was to demonstrate that the Spantech structures would behave in a similar fashion to a NATO standard igloo.

Preliminary conclusions are drawn from the trials and recommendations for incorporation of the results in the UK's ESTC explosive storage leaflets are given.

A full account of the trials and all the results will be given in the final Phase 4 Report to be published later in 1990.

ACKNOWLEDGEMENTS

The UK acknowledges the major contribution made by the Australian Department of Defence to the work reported here. The work was made possible by the use of the Woomera range and the support provided by and through the Directorate of Trials. In addition Waterways Experiment Station (WES) contributed significantly to the instrumentation task.

The trials were arranged through British Defence Research Scientific Staff Canberra (Mr G Burrows) with Director of Trials (Group Captain W Hall). The main contributors to the trials were the Australian Army (Project Officer, Major D Stuart and Project Officer Field, Major C Brereton with EOD Staff and detachments from 21 Construction Squadron), RMB Salisbury (under Mr G Appleby), OSD Salisbury (under Dr A Rye and Mr J Leach) and DSCW Personnel at Woomera (under Mr D Fail). The WES support staff were Mr J Ingram and Dr R Franco. Staff were also supplied from Australian Ordnance Factories to carry out weighing and sorting of fragments.

The trials would not have been possible without the additional aid of the Australian Department of Defence in supplying surplus anti-tank mines for use in the trials.

The trials proposals were discussed in detail and approved by the UK Explosives Storage and Transport Committee (ESTC), and its Explosion Effects Sub-committee.

1. BACKGROUND TO PHASE 4

1.1 The Explosion Effects Sub-Committee (EESC) of ESTC recommended, in the early 80's a programme of investigation of the effects of fragment and debris arising from stacks of ammunition inside typical UK traversed store-houses. This programme formed the basis of Phases 1-3 of the Joint Australian/UK Stack Fragmentation Trials conducted at Woomera between 1982 and 1988 and reported in References 1-4.

1.2 The work carried out in Phase 1-3 consolidated the information required by UK to verify and revise, where possible, existing distances for fragment and debris throw from limited (< 6000 kg) quantities of explosives in a variety of explosive storehouse structures. Although firm conclusions were offered the series of trials showed that it was not possible to take for granted the existing, often very subjective standards, for minimum fragment and debris hazards for explosives storage buildings. However there was, and still is, no intention to gather any more data for this part of the Quantity-Distance tables even although there were obviously still some unanswered questions regarding the protection required from fragmentation effects of concrete magazines.

1.3 Much work has been commissioned by the US DDESB to investigate the problems of open, untraversed stacks of fragmenting ammunition, in particular with respect to maximum and safe fragment distances. Similar work has been conducted for a variety of individual weapons by the UK Ordnance Board. However very little information exists for the situation when these same weapons and fragmenting ammunition are stored inside a structure which does more than simply provide weather protection. This was the primary reason for the UK conducting the initial series of Stack Fragmentation Trials.

1.4 However the question still remained whether the existing blast generated Quantity-Distances provide a sufficient degree of protection against fragment and debris effects for more typical storage quantities of several tens of tonnes NEQ of ammunition and explosives. Normally such quantities would be stored in igloos according to present day standards and the EESC considered that some work was needed to verify the existing Quantity-Distances for larger igloos in terms of debris and blast hazards. This becomes especially important when it is realised that AC 258 reduced the outside Quantity-Distances from the rear and side of igloos with NEQs of less than 45,000 kg, and it is not apparent that any consideration was given to the debris hazard posed by igloos. In addition, in the light of the UK's journey down the route of potential application of Risk Analysis techniques to the storage and handling of explosives it is even more essential to obtain some picture of the hazards posed by igloos , as well as other types of storage, at distances intermediate between ground zero and inhabited building distances, and beyond.

1.5 Consequently the author, as Technical Adviser (Explosives) to ESTC, opened negotiations in late 1988 with the Australian Department of Defence with a view to conducting a trial with a NATO Standard Igloo, loaded to some 75,000 kg NEQ, to investigate the effects from an accidental explosion of the contents of such a structure.

2. AIM OF PHASE 4

2.1 The objectives of the Phase 4 programme were to investigate the following aspects:

2.1.1 Break up of a UK designed NATO standard double bay igloo structure when exposed to the detonation of high explosives and the subsequent weight distribution, direction, distance and density of projections.

2.1.2 Validation of the blast pressure attenuation recommended by NATO AC 258 for the rear and side orientation of Igloo structures, particularly for Igloos containing in excess of 45,000 kg Net Explosives Quantity.

2.1.3 Validation of the pressure parameters used for the design of NATO Standard Igloos.

2.1.4 Comparison of free-field blast pressures produced by an explosion in an Igloo structure with those from an equivalent quantity detonated in free-air.

2.1.5 Measurement of initial Igloo structural and cover debris velocities resulting from an internal explosion.

3. PHASE 4 TRIAL SPECIFICATION

3.1 After extensive discussions in UK and Australia Phase 4 was finalised at a total of two tests. The first would be in a NATO standard double bay igloo and the second would be a detonation of an equal amount of explosives in the open. The details of the trial specification are as noted below.

Building Construction

3.2 Test 1 Donor : Standard UK reinforced concrete box, double bay, igloo structure to design as given at Annex A, with concrete floor slab.

3.3 Test 2 Donor : Concrete floor slab to simulate igloo floor used in Test 1.

3.4 After detailed discussion with the Australian department of Defence it was agreed to coalesce the Stack Fragmentation Trials Phase 4 with the Australian Explosive Store-house (ESH) Design Trial. The objectives of the ESH Design Trial were to :

3.4.1 Investigate, analyse and report upon the physical damage sustained by the ESH trial buildings as a result of the Stack Frag 4 explosion.

3.4.2 Assess and recommend any resultant design changes to the ESH trial buildings considered esssential for the satisfactory performance of their design function.

3.4.3 Investigate, analyse and report upon the blast overpressures recorded at selected positions adjacent to and upon the receptor buildings.

3.4.4 Investigate, analyse and report upon building displacement and acceleration records measured at selected positions within the receptor buildings.

3.5 As a result of this decision to coalesce the two trials, which produced significant savings to both the Australian Department of Defence and the UK Ministry of Defence, the receptor structure layout was finalised as follows:

3.5.1 Receptor 1 : Spantech structure, with standard 7 bar igloo head-wall and doors, constructed at 0.8 $Q^{1/3}$ front-to-rear wall separation from Donor structure to represent a NATO Standard Igloo in outline shape, situated at standard separation from an adjacent igloo structure.

3.5.2 Receptor 2 : Spantech structure, with standard 7 bar igloo head-wall and doors, constructed at 0.5 $Q^{1/3}$ side-to-side wall separation from Donor structure to represent a NATO Standard Igloo in outline shape, situated at standard separation from an adjacent igloo structure.

3.5.3 Receptor 3 : Spantech structure, with standard 7 bar igloo head-wall and doors, constructed at 0.8 $Q^{1/3}$ rear-to-front wall separation from Donor structure to represent a NATO Standard Igloo in outline shape, situated at standard separation from an adjacent igloo structure.

3.6 The basic Spantech structures used were as shown diagrammatically at Annex B.

Charges

3.7 Test 1 : Detonation of 75,000 kg TNT equivalent in Proposed Donor structure. Obselete anti-tank mines, TNT filled, were used for the donor charge. The charge was primed at some 600 points because of concerns that the mines might not all detonate simultaneously.

3.8 Test 2 : Detonation of 75,000 kg TNT equivalent in the open, with charge placed in as close proximity as possible to the position for Test 1 in order that the instrumentation layout used for Test 1 could be re-utilised as far as possible.

Measurement of Far Field Blast Pressures

3.9 Three lines of four gauges to measure the side-on overpressure in directions 40, 130 and 220 degrees with respect to ground zero, being to the front, side and rear respectively of the structure. The structure to be orientated so that the centre line of the structure lies in the NE/SW direction with the door pointing due NE. Details of the actual gauge layout are given schematically at Annex C.

Measurement of Blast Pressures on the receptor structures

3.10 The receptor structures were instrumented for blast measurement as per Ordnance Systems Division (OSD) Instrumentation Plan dated 5 Jan 90 (Ref 6). Annex D shows schematically the approximate positions of these gauges.

Internal Blast Pressure Measurements

3.11 Four (4) internal airblast gauges were located within the structure to measure internal blast pressures.

Accelerometer Measurements

3.12 In addition to the airblast pressure gauges, four (4) single axis accelerometers were installed on the top of the donor Igloo overburden to measure the acceleration of the cover breakup and initial debris velocities. Two (2) accelerometer packages were positioned near the top centre of the overburden, and the remaining two (2) packages were placed near the centre top edge of the overburden.

Photographic Coverage

3.13 Photographic coverage was provided as follows (Ref 7) :

3.13.1 High speed cine coverage with a field of view extending to 50 metres in front and to the rear of the structure. The intention being to attempt to ascertain the extent of initial venting from the front of the structure and through the earth cover.

3.13.2 High speed cine coverage with a field of view extending to 50 metres either side of the structure. Viewing to be from the rear of the structure to attempt to ascertain the extent of venting through the earth cover.

3.13.3 Wide angle coverage of the event out to 500 metres on both sides of the structure. This was intended to provide documentary coverage of the event but might show the trajectories of large debris.

3.13.4 Aerial photography of each test to document the spread of debris and dust cloud during the course of the explosion.

Debris Search Areas

3.14 The following search areas were established for collection of building debris as shown schematically at Annex E.

3.14.1 Four main fan searches in NE, SE, SW and NW directions. Sectors were 5 degrees either side of the main compass direction from 100 to 500 metres and a constant width (87.3 metres being the width of the 10 degree arc at 500 metres) from 500 to 1000 metres. All search areas were marked at 20 metre intervals from 100 to 1000 metres.

3.14.2 Four subsiduary radial search areas divided into 10 degree widths from 260 to 280, 400 to 420, 600 to 620 and 900 to 920 metres.

3.15 At a late stage in the planning of Phase 4 a suggestion was received from A Jenssen of the Norwegian Defence Construction Service to place marked objects on the roof and walls of the donor structure to allow observations to be made on the launch angle and velocity of the donor structure (Ref 10). To this end 24 steel cylinders, each 6 ins in diameter, length 6 ins and filled with concrete were prepared and placed on the walls and roof of the igloo on the earth overburden. In addition three plastic buckets filled with concrete were actually buried in the roof overburden.

4. IMPLEMENTATION OF PROPOSALS

4.1 The author opened negotiations with the Australian Department of Defence in late 1988 as a result of the initial recommendations for future work arising out of the preliminary report from the Stack Frag Phase 3 trials.

4.2 In early 1989 proposals were submitted to D Trials (Ref 5), as a direct result of a planning visit to Australia made by the author in Feb 89. These proposals were accepted in Nov 89 by D Trials, who had appointed a Trials Manager, initially Major R Baguley who had coordinated the Stack Frag Phase 3 trials but he was posted to other duties and replaced at a late stage in the trials planning by Major D Stuart, and a Project Officer Field, Major C Brereton, who had conducted Stack Frag Phase 3 in early 1988. At this time UK reached agreement with Waterways Experiment Station (WES) of Vicksburgh, USA, for the provision of additional instrumentation with particular reference to measurements inside and on top of the donor structure. This allowed the instrumentation plan to be extended significantly.

4.3 A further planning visit by the author in December 1989 resulted in a revised instrumentation plan which utilised effectively the support available from OSD and WES (Ref 6). During this planning visit the idea of coalescing Stack Frag 4 with the Explosive Store-house Design trial was agreed in principle.

4.4 Range Measurements Branch issued a trial instrumentation plan (Ref 7) as a result of the UK trials proposal and further discussions held during the planning visits by the author.

4.5 In Mar 90 D Trials issued a Defence Trial Directive which effectively combined the two trials (Ref 8). This was followed by the Trial Technical Instruction in early 1990 (Ref 9).

4.6 In the meantime a site for the trial was established some 25 km N of Woomera village, as shown at Annex I. Construction work commenced at Woomera in late 1989. The donor igloo was built by a local construction contractor at Woomera and the three Spantech structures were built under contract by Spantech to the Australian Services DOD Facilites and Property Division. All construction work was completed on schedule by late April 1990. The construction was supervised by representatives of the Australian Construction Services. (Ref 11)

4.7 All major trials support agencies were on site at DSC Woomera in late May 1990 and the donor charge was successfully detonated on 31 May 1990.

5. DEBRIS COLLECTION

5.1 Prior to the detonation the search areas shown in Annex E were marked out. It was then a relatively straightforward but nevertheless lengthy task to comb each marked area for debris which was collected into sandbags. These were then conveyed back to the site administration area, some 6 km distant, to be weighed and collated.

5.2 It was very quickly realised that there was an excessive amount of debris in the search areas close to ground zero, ie within 200-300 metres. In some cases it amounted to several hundred fragments with the minimum being around 100. In order to simplify the collation process it was decided to record only a total of the number of lethal fragments without recording each weight individually for these for these close-in high density areas. However in order to get an estimate of the weight distribution several of these search areas (c. 20% of the total were collated completely by weight).

5.3 It did not prove possible to collect all fragments from the search areas. Some were excessively large and heavy, typically 0.5m x 0.5m x 0.3m and some had impacted with such force that they were buried deep in the ground. All such fragments were recorded by dimension and listed as fragments in excess of 5kg weight.

5.4 The only fragments which were collected or identified were from the concrete structure itself. These included concrete, reinforcing bar and door elements. There was also a large amount of crater ejecta projected out to 200-300 metres from Ground Zero. This was not analysed directly by collection but is recognised as forming an important part of the overall debris density.

5.5 One other factor which proved to be of importance in the actual debris collection was the break-up of fragments on impact. Although this had been seen to a very limited degree in previous trials the degree of break-up and its widespread occurrence was not anticipated. The breakup complicated the collection in two major ways, viz:

> 5.5.1 Relatively small fragments (5-50kg in weight) which broke into several pieces on impact or when actually recovered. (Either at the time of recovery or during transport to weighing point). This led to a significant over-estimation of debris density at all ranges and its significance is discussed more fully in Section 6.

5.5.2 Very large (in excess of 0.5m x 0.5m x 0.3m) reinforced concrete sections which impacted and partially broke up spreading the resultant debris over large areas (typically 20m x 5m). In about 5-10% of the cases this was further complicated by the "fragment" bouncing after initial impact, finally coming to rest up to 25m from the original position. In a few instances there were several impact points as the fragment skipped or rolled to its final resting place.

6. DEBRIS ANALYSIS AND DISCUSSION

6.1 The debris was weighed and collated manually and then analysed by weight interval using a LOTUS 123 spreadsheet, in common with previous phases of the Stack Frag Trials.

6.2 As for previous phases it has been assumed that debris would be at or around its terminal velocity when it strikes the ground. Even given the situation of an untraversed igloo it is felt that this is not completely unrealistic since, on the three sides, the receptors provided some degree of traversing for the donor. Therefore it has been assumed that only metal debris over 75g or masonry debris over 150g would be potentially lethal and anything under these weights would be of little significance. As the collection progressed it transpired that there was very little debris under these particular weights, except where larger fragments had broken up on impact.

6.3 However there was left the overall problem of coping with the additional debris produced at all ranges, because of break-up either at impact or as a result of handling and transporting the collected debris. Although difficult to quantify the author estimated, by carrying out several sample surveys during the actual collection phase, that the total number of fragments were over-estimated in any particular sector by a factor of at least two. In some instances the over-estimation was probably significantly more than double and it is likely that there were some instances where it was less than double, although the occurrence of this latter category was not considered significant.

6.4 As a result it was decided to introduce the somewhat arbitrary reduction factor of 2 to produce the adjusted results. It must be stressed that this still gives a conservative estimate for the actual fragment density.

6.5 A further complication which has not been taken into account was the influence of crater ejecta at relatively close-in ranges, which is variable in size with a significant proportion being potentially lethal. The crater ejecta did, in some extreme cases, get projected to 700-800 metres. In most instances however the occurrence of crater ejecta was relatively evenly distributed out to 200-250 metres decreasing rapidly in density out to approximately 400 metres. It is estimated that up to 250 metres there was as much crater ejecta, which could be considered lethal since it was large lumps of baked clay, as there was building debris. Over the next 100 metres the significance of the crater ejecta reduced to about 25% of the building debris. As the range further increased it reduced rapidly and became non-existent, except for isolated instances, beyond 400 metres. Since the critical value for lethal fragment density was found to be in excess of this distance in the four principal search directions no account has been taken of the crater ejecta in the calculated fragment densities.

6.6 Like the building debris the crater ejecta was more pronounced in the directions normal to the original faces of the donor building. Outside the main 10 degree search angles there was very little crater ejecta beyond the 300 metre mark. At ranges intermediate between 100 and 300 metres in these areas there was a much greater concentration of crater ejecta than building debris but there was a lower absolute level than in the main search angles.

6.7 For ease of comparison the results of the four main directional (searches, ie 45, 135, 225 and 315°) are shown in Figure 6.1. The figure demonstrates emphatically the effect of orientation with respect to the donor as well as demonstrating the ranges at which the critical value of Lethal Fragment Density (LFD) is reached.

6.8 Figure 6.2 shows the variation of LFD with direction at a distance of 400-420m. Once again it shows the dramatic effect of orientation with the peaks occurring in a direction normal to any face of the building. Although the peaks are obvious at 45°, 225° and 315° the peak at 135° has been hidden by debris which has been projected between 55° and 125°. It is noticeable that this effect is not symmetrical, although the test layout was essentially so, and no explanation is offered for the phenomenon. Certainly beyond 400m there was no evidence of significant debris except in the sectors immediately adjacent, ie in the 55° and 125° directions. Perhaps there may have been a slight preferential propagation or venting effect in this direction but there is no other evidence to suggest this.

6.9 Note also the LFD does not immediately drop off outside the main directional search areas, although the effect is generally limited to the sector immediately adjacent to the main directions searched. In all directions, with the exception of the 55-125° sector, the LFD reduces rapidly to the critical value, although only in a few instances does it reduce to zero. It should be appreciated that 400m is less than half the Inhabited Building Distance for a 75,000 kg charge.

6.10 Figure 6.3 shows the variation with direction at a range of 600-620m. Note that the search was limited to the sector from 225° to 315° because of the large areas which had to be searched. Note also that the 235° and 305° areas are slightly larger than the nominal 10° because of the arrangement for searching in the main directional areas. This effect has been taken account of in the calculation of LFD.

6.11 No fragments were found from 245° through to 295°, validating further the directional cross effect seen in all the Stack Trials to-date. In no direction is the debris density of concern.

6.12 Figure 6.4 shows the variation of LFD with direction at a range of 900-920m. The search was limited to the sector from 315° through to 45° because of the large area to be searched. Again note that the 325° and 35° areas are larger than the others, being taken account of in the calculations.

6.13 In no direction is the density of concern although fragments were found in almost every area in comparison with the results given in para 6.10. This is probably the influence of the "unprotected" headwall generating more energetic fragments than those walls which were earth covered. There was no evidence to suggest that there were any fragments beyond this range in any direction other than that to the front of the donor igloo. However one concrete filled cylinder from the side wall of the igloo was found just beyond the searched areas.

6.14 As was originally anticipated the building doors were projected directly out to the front of the igloo. However they were very effectively fragmented by the explosion. Large pieces (over 0.5x0.5m in plan) were identified as part of the large fragment survey. This located some 28 pieces of door and door supports, accounting for about 50% of the total door material.

6.15 The ventilators from the rear part of the igloo roof were located in the 225° search fan at 200 and 440m. Additionally a further large metal plate was found at 230m in the 310° direction. This was probably one of the ventilator covers from the front headwall.

6.16 There is one final point which is worthy of mention. At 1200m distance, direction 50°, an impact point was discovered. A fan of debris was identified from here to approximately 1580m, the fan widening to c. 20m at its furthest extent. It appeared that all the debris in this fan originated from the initial impact and in summary there were some 17 large pieces of concrete (of mass over 1kg), 10 pieces of reinforcing bar and probably 2-3 dozen smaller pieces of concrete (less than the potentially lethal mass limit). It is suggested that all of this could have come from a section of concrete of approximate size 1.5x1x0.25m, its maximum size being estimated from the lengths of r/bars identified. Obviously this would have been a significant fragment of great interest and would be worthy of some further investigation. The fragments of interest are shown in Table 6.8 page 2 by the fragments marked with an asterisk.

6.17 As the size (and thus approximate mass) and final position are known for all these large pieces it should be possible to estimate the initial velocities and angles of projection for each fragment. Apart from the piece described at para 6.41 there was also another large piece of concrete, size 2x2x0.3m, which had obviously landed end on and then fallen over at distance 450m, direction 330°. It created an impact crater 0.5m deep. Again it is considered that the possible trajectory of this piece could be estimated with some potentially interesting results.

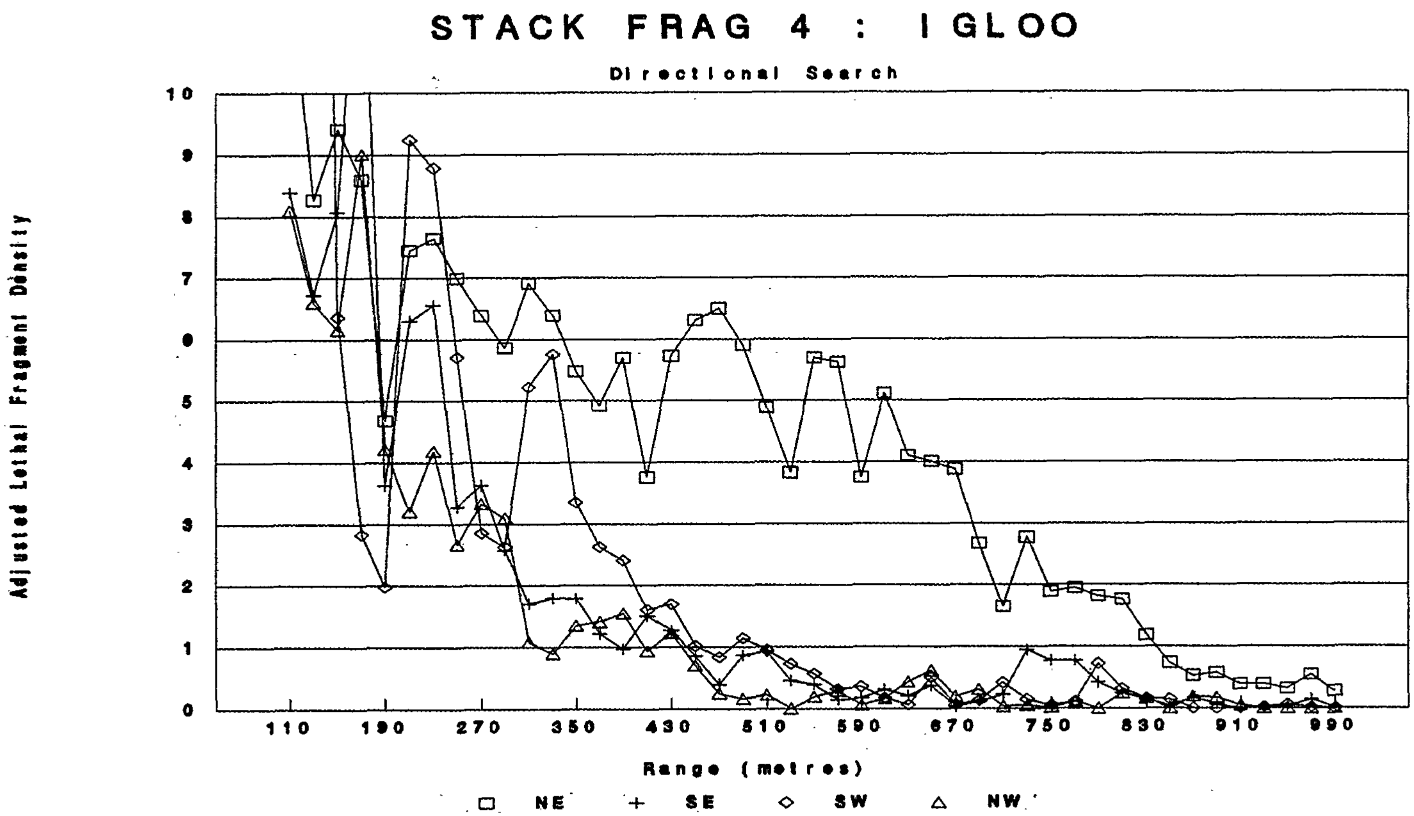
STACK FRAG 4 : IGLOO
Directional Search
Adjusted Lethal Fragment Density
0
1
2
3
4
5
6
7
8
9
10
110
190
270
350
430
510
590
670
750
830
910
990
Range (metres)
NE
SE
SW
NW

Figure 6.1

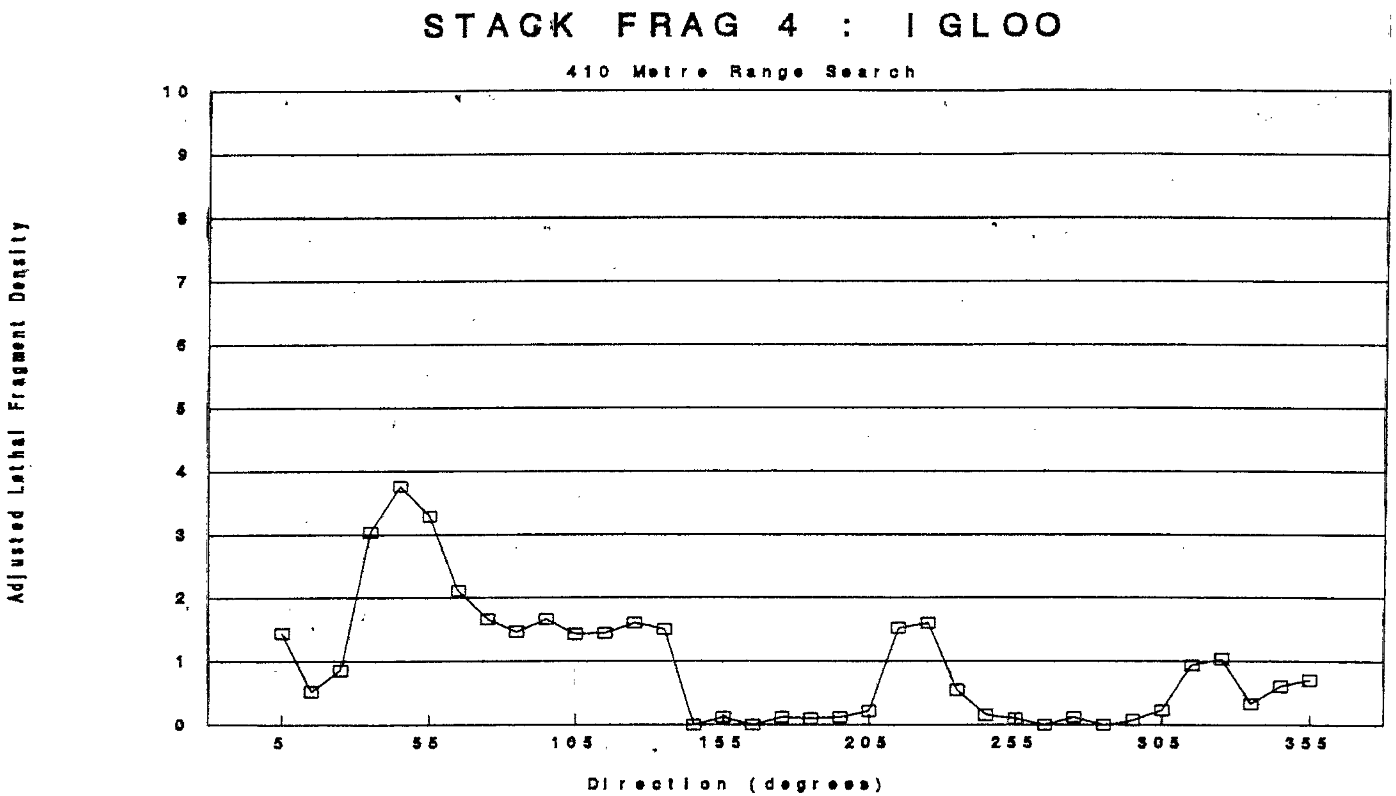
STACK FRAG 4 : IGLOO
410 Metre Range Search
Adjusted Lethal Fragment Density
Direction (degrees)
0
1
2
3
4
5
6
7
8
9
10
5
55
105
155
205
255
305
355

Figure 6.2

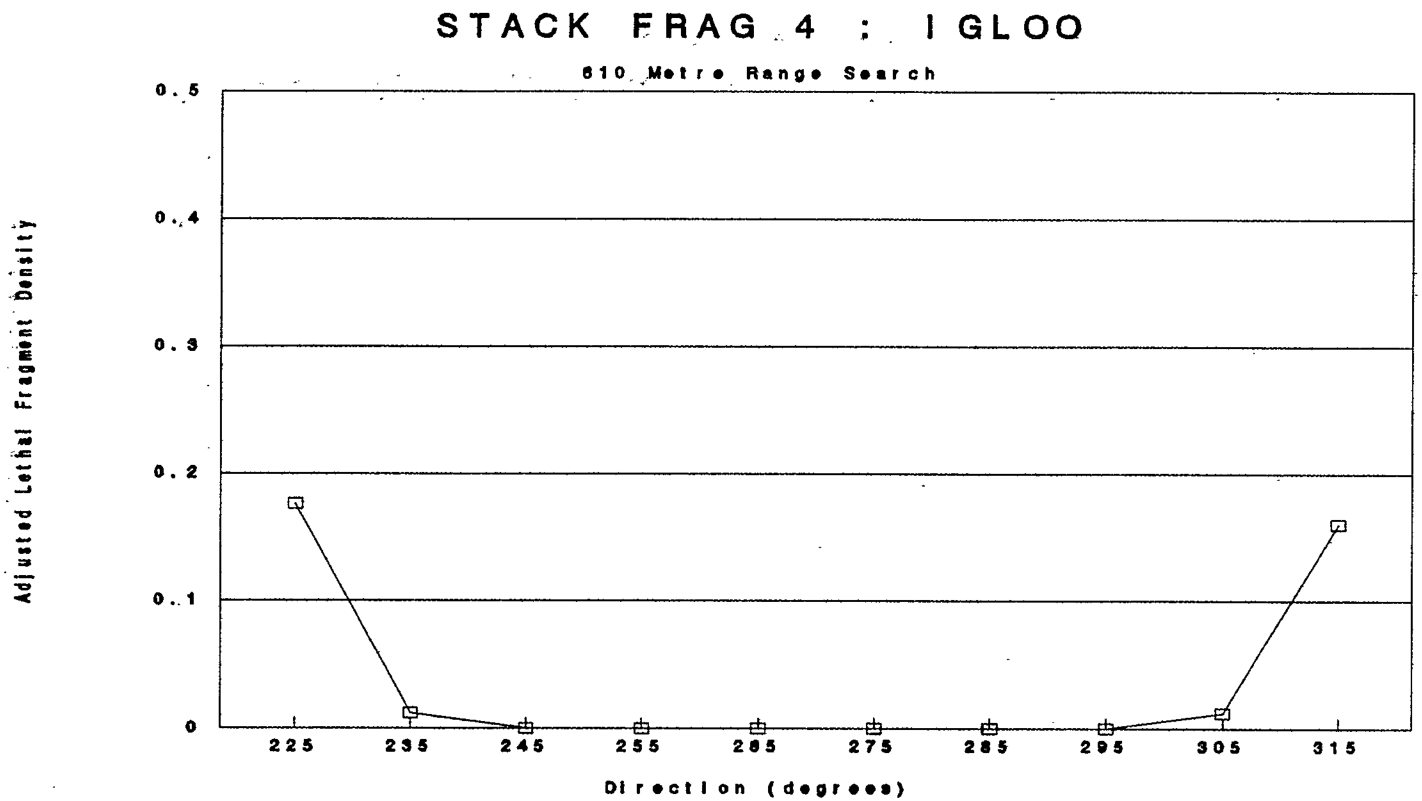
STACK FRAG 4 : IGLOO
610 Metre Range Search
Adjusted Lethal Fragment Density
0.5
0.4
0.3
0.2
0.1
0
225
235
245
255
265
275
285
295
305
315
Direction (degrees)

Figure 6.3

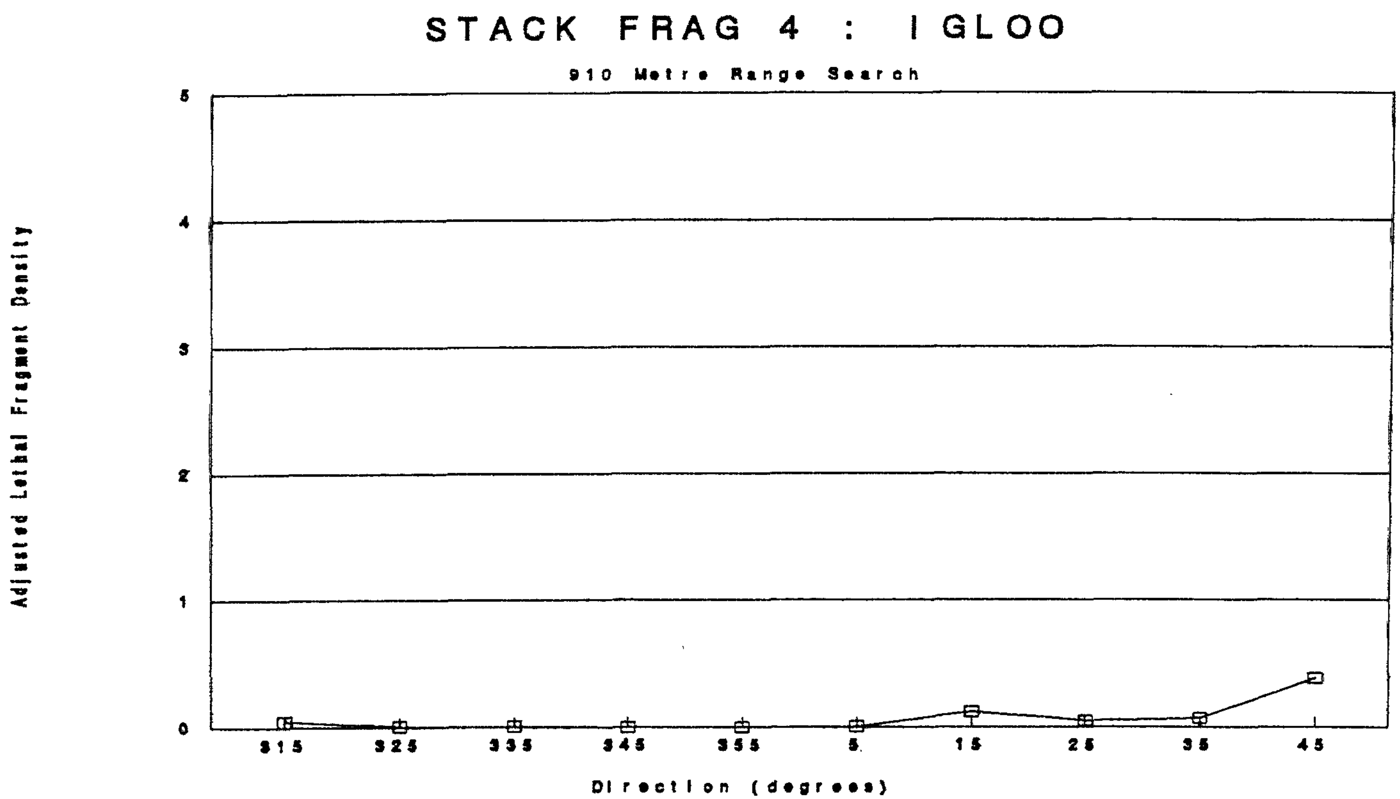

Figure 6.4

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7. CRATER

7.1 There was apparently a double crater created as a result of the explosion in the donor igloo. The position of each of the constituent craters agreed well with the positions of the two original stacks of mines in the igloo. There had been some upheaval of the portion of the floor in between the two stacks.

7.2 There was a very large lip around the crater which extended vertically up to 3 metres above the original ground level and horizontally out to 5 metres beyond the edge of the crater proper. As noted in the discussions on debris the debris from the crater extended into the far field as far out as 400 metres with the bulk being inside 250 metres.

7.3 The crater is estimated as being some 36 metres long by 28 metres wide at its maximum. This compares favourably with a calculated crater diameter of 42 metres. However the depth does not exceed 2 metres at any point and is more typically 1 to 1.5 metres below the original ground level. However each of the two individual craters is approximately 20m long by 7m wide by 2m deep. As each stack was 37,500 kg NEQ the theoretical size of each of these individual craters would have been 33m in diameter

7.4 It is difficult to make informed comment on the appearance of the crater. The instrumentation deployed indicated that there was a full yield of the 75,000 kg TNT charge. There was a considerable amount of concrete in the floor and foundations of the igloo, estimated to be several hundred tonnes. A lot of this concrete was still apparent in the crater after the explosion. Undoubtedly a significant proportion of the energy normally available for excavating the crater was used in moving the concrete in the floor and foundations. Hence a much smaller or shallower crater would be expected as was found in this trial.

7.5 The total volume of the crater is estimated conservatively at only some 600-1000 m^3. Theoretically it would have been expected to be roughly hemispherical with a maximum volume of about 19,000 m^3.

8. BLAST INSTRUMENTATION

Far Field Pressure Measurement

8.1 WES Results : The results are given in the table below where the orientation front, side or rear refers to the orientation with respect to the donor igloo with front meaning the gauge line running away from the front side of the igloo. The full results with descriptions of the techniques used and copies of the individual gauge pressure-time histories are given in Reference 13.

Orientation	Distance (m)	Pressure (psi) Measured	Estimated
Front	940	0.65	0.75
Front	620	1.1	1.5
Front	340	2.5	3
Front	90	17	30
Side	490	1.45	1.5
Side	270	3	3
Side	80	12	30
Rear	390	1.45	1.5
Rear	215	3.5	3

Note that it had been intended to measure the pressure at four points on all three radials. Because of the limited time available to the WES team some of the more distant positions were not instrumented.

8.2 OSD Results : The results are given in the table below where the orientation front, side or rear refers to the orientation with respect to the donor igloo with front meaning the gauge line running away from the front side of the igloo. The full results with descriptions of the techniques used and copies of the individual gauge pressure-time histories are given in Reference 14.

Orientation	Distance (m)	Pressure (psi) Measured	Estimated
Front	940	0.95	0.75
Front	620	1.22	1.5
Front	340	2.74	3
Front	100	n/r	30
Side	750	0.98	0.75
Side	500	1.56	1.5
Side	270	3.07	3
Side	80	12.85	30
Rear	590	0.9	0.75
Rear	390	1.75	1.5
Rear	215	3.46	3
Rear	65	18.21	30

8.3 As can be seen fairly readily from the results in paras 8.1 and 8.2 the measured results compare very favourably with the estimated results. For the closest gauges on all the radials the measured pressure was about half that originally estimated. At the two intermediate positions on each radial, corresponding to Explosives Workshop and Public Traffic Route distances, the measured results match almost exactly the predictions.

8.4 At the Inhabited Building Distance (IBD) however there is somewhat of a conflict. The only WES result which is applicable matches the prediction but the three OSD results on the three radials all exceed the predictions by a factor of between 27% and 31%. This is well outside what could be regarded as experimental error or variation. However they do not appear to be consistent with the other pressure measurements since taken at face value they appear to indicate some general pressure increase at IBD, even on the open, unattenuated side. Had these been matched with an equivalent increase at the closer in gauges then some store should be put by them. Since this is not the case it is suggested that their absolute values should be effectively put to one side until some satisfactory explanation can be put forward for the apparent variation. However since the measured pressure at the IBD on the open side is identical to that measured at the suggested IBDs on the other two sides, this can still be used to verify that the IBD on each of the radials should be at the suggested positions. It is considered that this is further justified by the fact that the WES gauge on the open side matched the predicted pressure very closely, being some 13% low which is considered to be within the experimental error for such a measurement.

8.5 This effectively means that there is a significant pressure attenuation to the side and rear of a UK standard double-bay box igloo containing 75,000 kg NEQ which is equivalent to that given by AC 258 for standard NATO igloos containing less than 45,000 kg NEQ. It should be noted that the attenuation is significant at all ranges, being greatest close in.

8.6 However further testing, preferably at model scales of not less than 1/5 should be conducted to provide statistically more meaningfull results particularly at the Inhabited Building Distances. This should give some indication that the results obtained by OSD at this distance, in particular, can be considered spurious.

Donor Structure Instrumentation

8.7 A total of four internal blast gauges were fitted to the donor igloo in an attempt to measure the internal blast loadings. The three gauge packages were recovered that had originally been installed in the rear and side walls. However as noted earlier the instrument packages were recovered separated from their protective steel cylinders. As a result only the sidewall centre gauge produced a recording which could be interpreted. This indicated a peak pressure of some 10,000 psi with a duration of some 20-25 msec.

8.8 The gauge mounted in the roof of the donor was never recovered but a second instrument package had been connected externally to a second gauge in the same package. The recorder was actually located outside the igloo and was subsequently recovered and interrogated. Although the signal was abruptly cut at some 16.6 msec after detonation, when the connection was broken because of projection of the instrument package, a useful recording was obtained. This indicated that a peak pressure in excess of 18,000 psi was achieved. The pressure was still rising when the connection was broken so there is no clear indication what the final pressure would have been.

8.9 Although the results will not be directly applicable because of their limited nature the exercise of measuring the internal blast loads was well worth while. In particular it has given WES the opportunity to test their gauges in a harsh debris environment and will lead to a redesign of the actual packages to ensure that they remain intact in future tests.

8.10 The problem of gauge location remains difficult. In total five gauges were unaccounted for during this test, the roof mounted internal blast gauge and the four external mounted accelerometers. It is considered that these along with most of the unrecovered cylinders which were also placed on the roof are most probably buried in the debris which was in and around the crater.

9. DETERMINATION OF LAUNCH ANGLES AND VELOCITIES OF DONOR BUILDING DEBRIS

9.1 As advised in Ref 10 some 24 steel cylinders, each 6ins diameter by 6ins in length, were filled with concrete and made identifiable by painting with Scotchlight and embossing a reference number on the outer surface. Eleven were placed on top of the roof cover of the donor igloo, and the remaining thirteen of the side and rear earth cover.

9.2 At the date of writing (June 90) only seven of the twenty four cylinders had been recovered, despite a relatively intensive search of the area within 1000 metres of ground zero. As the cylinders found were at ranges between 580 and 1000 metres and appeared to form a reasonably distinct pattern of distribution the search was intensified in the areas where the remaining cylinders could be expected to have landed. However no more cylinders were recovered.

10. CONCLUSIONS

10.1 Undoubtedly the test was an unqualified success. It achieved virtually all the original aims of the trial with the exception of the measurement of the cover debris velocities by means of externally mounted accelerometers. As these were never recovered obviously no results were obtained (para 8.10)

10.2 Also only a limited amount of information was obtained from the internally mounted blast gauges. However these were still adjudged to have been successful in that some measurements were obtained but more importantly the gauges can be redesigned to cope better with similar conditions in the future. (paras 8.7-8.8)

10.3 The measurement of the far field pressures was very successful and has confirmed that the UK double bay box igloo provides a similar level of attenuation for the blast originating from a 75,000 kg NEQ charge as that already invoked by AC 258 for standard igloos with less than 45,000 kg NEQ. Further that such attenuations can be extended to include reductions in the quantity-distances for process building distances and public traffic route distances as well as IBD. (para 8.3-8.5)

10.4 However further testing should be carried out at model scales to provide better staistical information on which to assess the results, particularly those obtained at Inhabited Building Distance. (para 8.6)

10.5 The results of the extensive debris search, collection and analysis has demonstrated that the debris hazard from a UK double-bay box igloo reaches tolerable levels (defined as 1 potentially lethal fragment per 56 m^2) well inside the IBDs which would be proposed as a result of the pressure measurements given in Section 8. The equivalent pressure and debris IBDs are given in the table below for ease of comparison:

Orientation	Pressure IBD m	$Q^{1/3}$ Factor	Debris IBD
Front	940	22.2	850 (para 6.12)
Side	750	18	450 (paras 6.15, 6.24)
Rear	590	14	510 (para 6.20)

10.6 The crater generated as a result of the explosion was significantly shallower than expected and overall generally smaller in dimensions than the theoretically calculated size. This was considered to be not unusual because of the very large amounts of concrete in the floor and foundations of the donor igloo. (paras 7.4-7.5)

11. RECOMMENDATIONS

11.1 The quantity distances currently used by UK to the side and rear of the UK standard box igloo should be reduced as follows for UK standard igloos which contain up to 75,000 kg NEQ :

Orientation	Q-D Purpose	Current	Proposed
Side	Process Building	$8.0Q^{1/3}$	$6.5Q^{1/3}$
Side	Public Traffic Route	$14.7Q^{1/3}$	$11.9Q^{1/3}$
Side	Inhabited Building	$22.2Q^{1/3}$	$18.0Q^{1/3}$
Rear	Process Building	$8.0Q^{1/3}$	$5.0Q^{1/3}$
Rear	Public Traffic Route	$14.7Q^{1/3}$	$9.3Q^{1/3}$
Rear	Inhabited Building	$22.2Q^{1/3}$	$14.0Q^{1/3}$
Front	Process Building	$8.0Q^{1/3}$	$8.0Q^{1/3}$
Front	Public Traffic Route	$14.7Q^{1/3}$	$14.7Q^{1/3}$
Front	Inhabited Building	$22.2Q^{1/3}$	$22.2Q^{1/3}$

Note that as at present all igloo Q-Ds are subject to a minimum 400m distance for debris throw, unless tests have demonstrated that a lesser distance may be used for such purposes.

11.2 It is recommended that further model testing should be carried out to ascertain that the pressure levels measured in the test are correct particularly in view of the conflict of the pressures measured at the Inhabited Building Distances on all three orientations.

REFERENCES

1. Joint Australian/UK Stack Fragmentation Trials Phase 1 Report - F Bowman, J Henderson et al - D/Safety/11/55/22 undated

2. Joint Australian/UK Stack Fragmentation Trials Phase 1B Preliminary Report - J Henderson - ESTC/162/EE/7, WP7

3. Joint Australian/UK Stack Fragmentation Trials Phase 2 Report - J Henderson et al - D/Safety/11/55/22 dated August 1985

4. Joint Australian/UK Stack Fragmentation Trials Phase 3 Report - J Henderson - D/ESTC/14/1/8/2 dated May 1990

5. Joint Australian/UK Stack Fragmentation Trials Phase 4 Proposal - D/Safety/11/55/22 dated 14 Feb 1989

6. OSD Instrumentation Plan dated 5 January 1990.

7. Range Measurements Branch Trial Instrumentation Plan RMB-IPLAN-OI-029 Issue 1 dated 15 Feb 1990.

8. Defence Trial Directive for Coalesced Defence Trials 6/445 and 6/447 - DST 88/4398/6 dated 23 Mar 90.

9. D Trials Technical Instruction DST 88/4398/7 dated 6 Apr 90.

10. Letter Jenssen/Rees dated 28 Mar 90.

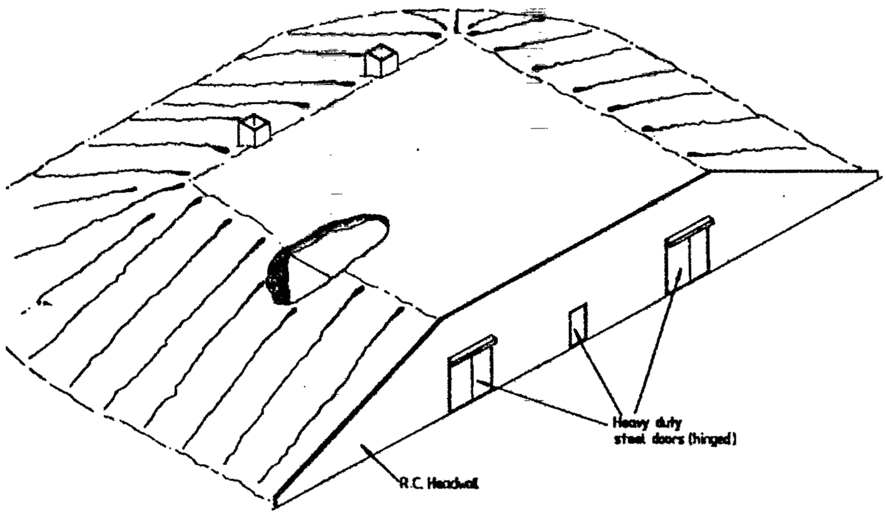
11. ACS Construction Report.

12. ESH Design Trial Report.

13. WES INstrumentation Report.

14. OSD Instrumentation Report.

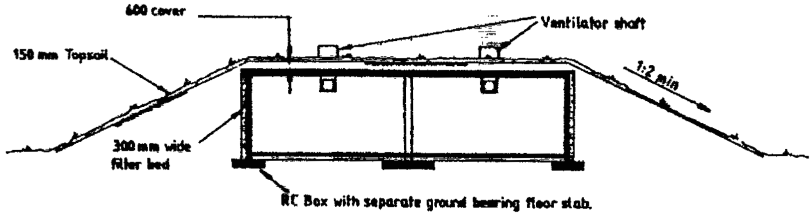
ANNEX A : NATO STANDARD DOUBLE BAY IGLOO



INTERNAL DIMENSIONS :- Length 16·00 m, Width 18·00 m, Height 4·80 m.

STORAGE CAPACITY :- 2×(4×10×3) = 240 standard NATO pallets.

EXPLOSIVE LIMIT :- 75,000 kg. TNT Equivalent



NOTE :- For details see D.O.E. layout Drg

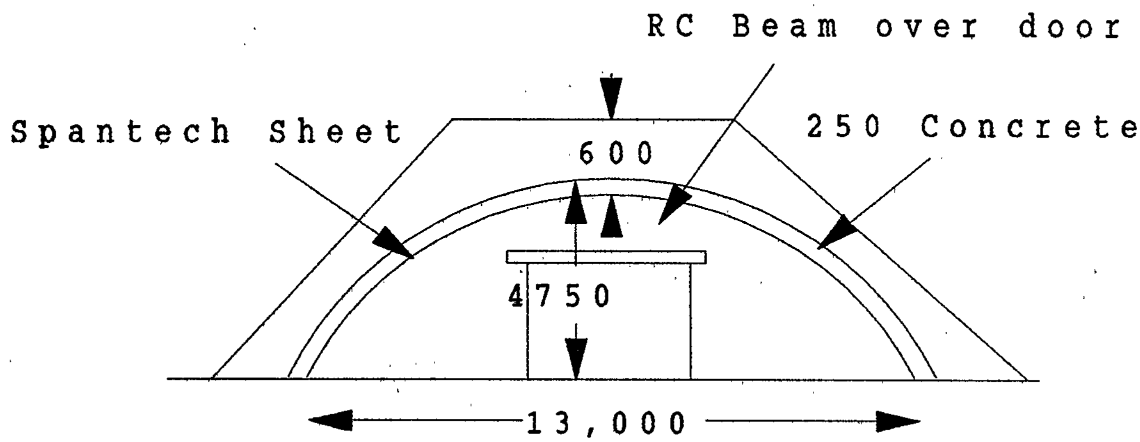
APPROVED IGLOOS - U.K. BOX (DOUBLE BAY)

ANNEX B : SPANTECH STRUCTURE

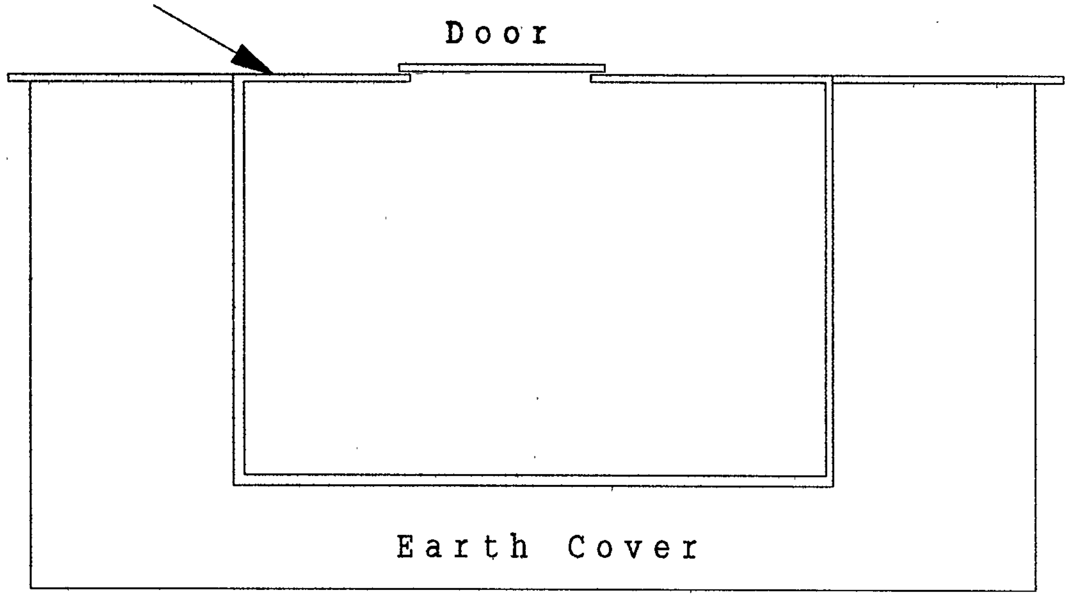
Schematic Spantech Design

Not to scale

SECTION



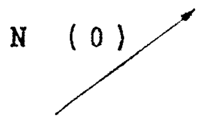
PART PLAN



ANNEX C : SCHEMATIC GAUGE LAYOUT FOR FAR FIELD

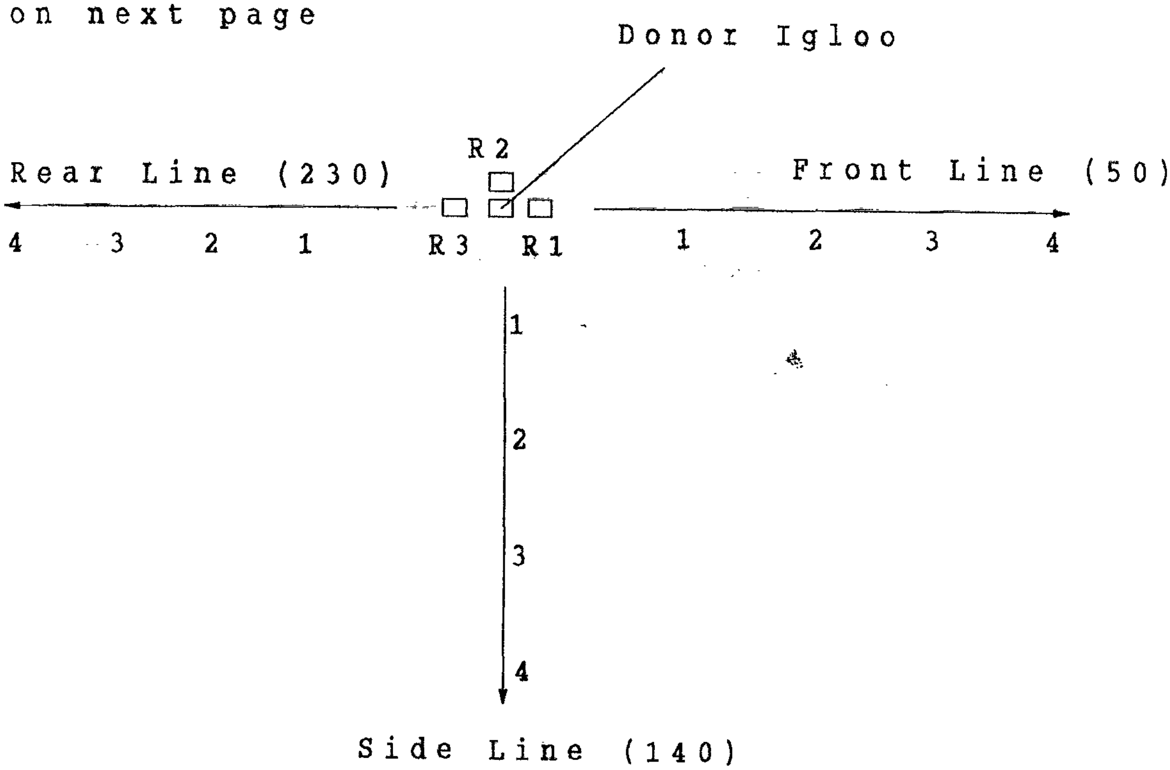
Diagrammatic Only

Not to scale

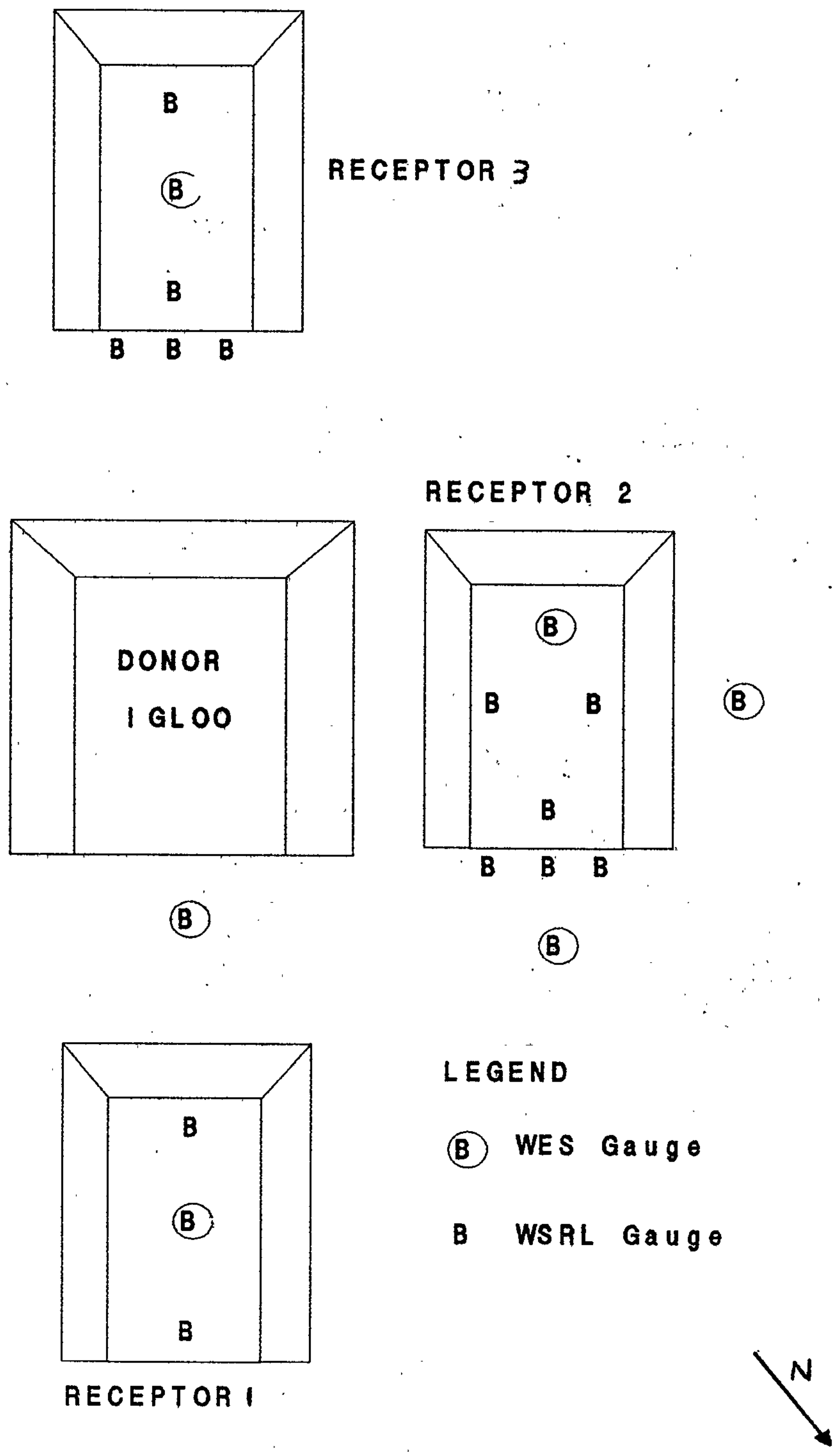


Numbers in Brackets are direction in degrees

Numbers 1-4 signify gauge positions detailed on next page



ANNEX D : SCHEMATIC GAUGE LAYOUT ON RECEPTOR STRUCTURES



ANNEX E : DEBRIS SEARCH PATTERN